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FRICTION OF ROTATING BAND MATERIAL DURING ENGRAVING AND INITIAL PROJECTILE TRAVEL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The sliding characteristics and coefficients of friction of rotating band and potential rotating band material on steel were studied in the laboratory at velocities corresponding with projectile velocities near the origin-of-rifling. The band materials investigated were gilding metal, 7075 aluminum alloy, AZ61A magnesium alloy, sintered iron, soft iron, nylon 6-6, and vulcanized fiber. It is possible to draw a number of conclusions and make a number

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Vulcanized Fiber, Friction on Gun Steel

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of conjectures about the engraving and initial travel of cannon projectiles from the results of this study. A comparison of the different sliding characteristics and laboratory friction coefficients provides insight into the behavior of projectiles and will help to allow the design of rotating bands without the expensive extensive firing of an actual cannon.

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INTRODUCTION

The most important missing data required to calculate the in-bore motion of a projectile in a cannon tube is the friction coefficient of the band material on gun steel. While the bourrelet of the projectile also slides on the gun bore, its bearing pressure is low because of inertial effects and because there is no dimensional interference as there is in the case of the rotating bands. The friction of rotating bands in the region of the origin-of-rifling is particularly important. This friction has a great effect on the "shot-start" pressure required for initial movement of the projectile and also on the motion of the projectile during its first inch of travel. This is important for the "sticker" problem and, indeed, it is believed for many other problems which are only manifested well down-bore. Friction during initial travel of the projectile is very important as far as the inbore motion of the projectile is concerned. A comparison of friction coefficients in this region for different band materials would allow projectile designers to get an insight into the behaviors of their projectiles and should even help them to design rotating bands without the expensive extensive firing of an actual cannon. The experiments reported here were designed to obtain this important initial coefficient of friction data for rotating band and potential rotating band material.

Friction at the origin-of-rifling and for the first inch of projectile travel where the velocity is relatively low can be determined with a more-or-less conventional pin-on-disk wear machine. Of course, the sliding speed used will be higher than those commonly employed but they are well within the capability of this kind of friction and wear machine without the very special modifications required for determinations at very high sliding speeds. Further down-bore, the projectile develops a thin surface layer of molten material; after this, the coefficient of friction becomes that characteristic of melt lubrication (about 0.05).[1] The coefficient of friction for melt lubrication is dependent on the specific material of the rotating band only so far as it controls the thickness of the molten surface layer formed for a given rate of heat input and the viscosity of this layer.[2] Friction values obtained with a pin-on-disk machine at these high sliding velocities are much too high because the leading edge of the pin is not melt-lubricated owing to the pin's necessarily relatively small diameter.[2,3] It is believed that meaningful friction data at the very high sliding speeds reached down-bore in a cannon tube can only be obtained with an actual cannon.

An estimate of the amount of band material transferred to the gun bore near the origin-of-rifling and the smoothness of initial sliding of the projectile can also be obtained from pin-on-disk experiments. The problems associated with transfer here are dependent on the character of the material transferred and not just on the amount transferred. Clearly, the effect of hard lumps of iron adhering to the bore will be greatly different from that of lumps of vulcanized fiber. Furthermore,

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[1]Montgomery, R. S., Surface Melting of Rotating Bands, Wear 38, 235-243 (1976).

[2]Montgomery, R. S., Projectile Lubrication by Melting Rotating Bands, Wear 39, 181-183 (1976).

[3]Montgomery, R. S., Friction and Wear at High Sliding Speeds, Wear 36, 275-298 (1976).

it should be pointed out that band wear in this region will be very different from band wear experienced during travel through the remainder of the gun tube. It has been shown that this wear is largely governed by the melting point and thermal conductivity of the band material.[3]

EXPERIMENTAL METHOD

The experimental coefficients of friction were determined with a "pin-on-disk" type friction and wear machine. With this machine, a pin is pressed against the surface of a rotating disk and the friction force measured. Although it was not done in this series of experiments, wear rate can also be determined by weight loss of the pin. The disk was made of AISI 4340 steel which approximates the composition of conventional gun steel. The pins were made of the rotating band or potential rotating band material to be tested. In this work, the friction of pins of gilding metal, 7075 aluminum alloy, AZ61A magnesium alloy, sintered iron, soft iron, nylon 6-6, and vulcanized fiber was studied. Gilding metal, as used in munitions, is an alloy of copper with 10% zinc. The compositions of the alloys are given in Table 1. Vulcanized fiber is a product of partially regenerated cellulose in which the fibrous structure is retained in varying degrees, depending on the fiber used in its manufacture. The gilding metal pins were made from a band blank for the 155mm M107 projectile; the aluminum alloy pins were made from the base of a sabot for the 105mm M392A2 APDS projectile assembly; the magnesium alloy pins were made from the sabot in the petal region

[3]Montgomery, R. S., Friction and Wear at High Sliding Speeds, Wear 36, 275-298 (1976).

from the same projectile assembly; the sintered iron pins were made from a band blank for the 152mm M409A1 projectile; the soft iron pins were made from an experimental band blank (FA-E-409) for the 8" XM711 projectile; and the nylon and vulcanized fiber pins were made from the centering and rotating bands, respectively, of a U.K. produced, L-36 APDS projectile assembly. The L-36 is essentially identical with the US M392A2 projectile assembly. In the case of nonmetallic materials where directionality may be important, small pieces of the material were cemented to the ends of steel pins so that the sliding surfaces would be identical with those of actual bands in a cannon tube.

TABLE 1. COMPOSITIONS OF ALLOYS INVESTIGATED

Alloy	Chemical Composition (wt. percent)
Gilding metal	Zn, 10; Cu, Bal.
7075 Aluminum	Zn, 5.58; Mg, 2.15; Cu, 1.82; Fe, 0.23; Cr, 0.18; Al, Bal.
AZ61A Magnesium	Al, 5.7-7.2; Zn, 0.4-1.5; Mg, Bal.

The design of the test machine was fairly typical. The differences between it and the usual pin-on-disk machines are related to the extremely soft and rapid-wearing natures of the materials used for the pins. The disk was 12 in. in diameter and 1 1/4 in. thick. It was designed to be of relatively large mass so that its rotational speed would not change during the experiment; speed changes could not be adequately measured because of the very short duration of the experiment. The rotational speed of the disk was obtained by measuring the rate of light pulses through eight equally spaced holes around the periphery of the disk. The determinations described in this report were made at sliding speeds of 67 and 120 in/sec. This corresponds to projectile velocities close to the origin-of-rifling in a cannon.

The method used for bringing the pin into contact with the disk for an extremely short time was novel. The pin was loaded with a "nutcracker" arrangement by means of a pneumatic cylinder fastened to the end of the loading arm. The arm was continually loaded but was supported by means of a rotating cam and sear arrangement so that the pin was out of contact with the disk. When the sear was triggered, the pin was let down a very short distance into contact with the disk and then quickly picked up again by the rotating cam. The sear then reengaged thereby preventing the pin from again contacting the disk. Typical contact times were about 0.1 sec. The shortness of contact time was limited by the time required for lowering the pin on the disk since the loading arm carrying the pin had considerable inertia.

The pin diameter used for most of the experiments was 0.187 in. A pin diameter of 0.156 in. was used for a few initial experiments until it was decided that this smaller diameter led to problems arising from distortion of the pin. One pin was used for a number of experiments; the exact number depended on its wear rate. The values of both load and friction force were obtained from outputs from strain gages. The bearing load was obtained from a commercial strain-gaged stud located between the pin-holder and the load arm. The friction force was obtained from strain gages mounted on the leading and trailing surfaces of the pin-holder which measured deflection in the direction of sliding. The outputs of the strain gages were measured with an oscilloscope because of the extremely short duration of that portion of the experiment producing friction data (60 ms or much less). The load and friction traces were recorded photographically, the values measured, and the coefficients of friction computed for the various bearing pressures. The length of the pin projecting from the pin-holder during the experiment was measured and taken into account in the computation of the friction force. This length affected the calibration of the strain gages. With this apparatus, it was not possible to obtain friction values at very high bearing pressures because of distortion of the relatively small diameter pins and because of the time required to develop high loads on the pins. In an actual cannon, the band material is confined so the band pressures during engraving usually are three or more times the values obtained with this pin-on-disk apparatus.

The friction data reported at this time are for band material sliding on a smooth, fresh steel surface. The situation in an actual cannon is more complex; the tube surface may not be smooth and it is certainly contaminated with powder residue and band material from previous rounds. In general, roughness, whether due to the counter-surface itself or to adhering band material, increases the value of the coefficient of friction while surface contamination lowers it. In any case, a smooth, fresh steel surface is well-characterized and reproducible and data obtained with it will provide a guide to the actual friction of band material on the bore of a cannon tube. The fresh steel surface on the disk was produced by first removing all traces of transferred band material by abrading with 100 grit emery cloth while rotating the disk at speed. The disk was then polished with 400 grit emery cloth at speed, and, finally, was wiped with soft paper to remove any traces of grit, etc. also at speed. In the initial experiments, the disk was also wiped with soft paper wetted with petroleum ether after being wiped with dry paper. This was done in order to remove any possible traces of oily contamination from the surface. Apparently, it was not required since it made no difference in the friction data; this step was not used for most of the experiments.

Usually, data from the first experiment with a fresh pin were different from the other data and so were discarded. Only friction data from sliding of the pin on a fresh steel surface were used; data obtained near the end of an experiment where the pin was sliding on a surface which it had previously contacted were not used. The coefficient of friction values are reported to three significant figures except where there was some oscillation where they are reported to two.

RESULTS

In addition to the friction data, the experiments provided observations on smoothness of sliding, wear rate of the pin material, and amount and character of the pin material transferred to the steel disk. These observations pertain to the relatively low velocities of 67 and 120 in/sec which corresponds to projectile velocities close to the origin-of-rifling. The characteristics of the sliding will be different down-bore where sliding speed is much greater and the mechanism of wear is different.

Gilding Metal

The sliding of gilding metal on steel appeared smooth but there was a rapid oscillation of the load oscilloscope trace at the higher loads. There was less oscillation in the friction force trace. The wear rate at these bearing loads and sliding velocities was low and there was only a small amount of smooth transfer.

At very low bearing pressures both sliding velocities produced the same friction but as the pressure increased, the friction for the 120 in/sec sliding velocity became lower than that for the 67 in/sec velocity. The coefficient varied from about 0.50 at a bearing pressure of 1.5 Ksi to about 0.27 and 0.23 at 9.0 Ksi for velocities of 67 and 120 in/sec, respectively (see Table 2 and Figure 1).

7075 Aluminum Alloy

Sliding was smooth and there was generally only a small amount of smooth transfer of aluminum to the steel disk although there was sometimes oscillation like that of gilding metal. The wear rate was low.

The same coefficient of friction was obtained with both sliding velocities. It varied from about 0.33 at a bearing pressure of 2.0 Ksi to 0.28 at 11.0 Ksi. The friction was the highest obtained with any of the materials at the higher bearing pressures (see Table 3 and Figure 2).

TABLE 2. FRICTION OF GILDING METAL SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
8.6	0.290	2.0	0.413
9.2	0.25	2.0	0.389
9.4	0.27	2.1	0.400
9.6	0.23	2.3	0.394
9.6	0.23	2.5	0.371
9.5	0.24	2.4	0.386
10.5	0.25	2.7	0.424
10.5	0.27	2.4	0.408
4.2	0.338	2.8	0.375
4.5	0.327	2.7	0.377
4.1	0.342	5.7	0.34
5.0	0.312	6.2	0.30
4.6	0.362	6.1	0.28
5.0	0.371	6.1	0.28
4.7	0.358	8.2	0.28
4.7	0.383	8.3	0.29
5.0	0.374	7.9	0.29
5.0	0.385	8.0	0.29
5.0	0.387	6.1	0.357
4.8	0.377	6.2	0.382
3.8	0.361	6.4	0.369
4.4	0.322	6.2	0.382
3.9	0.353	6.6	0.355
4.3	0.323	6.7	0.345
3.4	0.370	6.7	0.345
2.9	0.398	6.6	0.33
3.8	0.393	7.5	0.32
3.8	0.393	7.6	0.32
3.6	0.413	7.7	0.31
3.9	0.382	7.5	0.32
2.9	0.334	7.6	0.32
3.1	0.335	4.8	0.392
3.2	0.388	4.2	0.421
3.6	0.323	4.4	0.43
2.7	0.424	4.8	0.39
3.6	0.328	4.8	0.40
3.3	0.357	4.7	0.41
3.5	0.361	4.5	0.424
3.3	0.357	3.4	0.444
1.5	0.483	3.4	0.460
1.9	0.442	3.4	0.475
1.8	0.431	3.4	0.465

TABLE 2. FRICTION OF GILDING METAL SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction
3.2	0.481
3.5	0.468
6.2	0.332
6.8	0.30
7.5	0.27
7.1	0.28
7.4	0.26
7.5	0.27
7.6	0.27
7.6	0.27
7.8	0.26
7.8	0.28
7.8	0.29
6.3	0.289
6.3	0.334
4.8	0.464
5.4	0.434
5.0	0.525
5.6	0.453

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
6.3	0.20	7.6	0.23
6.3	0.18	2.8	0.283
5.7	0.20	3.2	0.284
6.9	0.18	3.4	0.265
7.1	0.20	4.1	0.228
7.0	0.21	3.4	0.265
7.0	0.20	4.3	0.234
7.0	0.18	3.9	0.314
6.9	0.19	2.0	0.425
7.0	0.20	2.7	0.320
7.1	0.23	3.0	0.270
7.8	0.24	2.8	0.317
7.7	0.19	2.3	0.475
7.9	0.19	2.8	0.406

TABLE 2. FRICTION OF GILDING METAL SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
1.6	0.541	2.4	0.436
1.8	0.521	5.5	0.32
2.1	0.357	6.5	0.26
4.4	0.290	6.6	0.28
5.2	0.301	4.6	0.41
4.4	0.352	5.6	0.32
5.0	0.315	6.2	0.30
5.2	0.28	6.1	0.31
6.2	0.21	3.5	0.442
5.0	0.27	3.9	0.378
3.3	0.363	6.2	0.277
3.2	0.378	7.8	0.22
4.0	0.294	7.8	0.28
4.4	0.240	8.1	0.27
4.1	0.358	7.9	0.27
4.1	0.255	5.8	0.382
4.5	0.327	6.3	0.35
2.6	0.431	7.6	0.29
2.3	0.498	7.4	0.34
2.4	0.436	6.8	0.35
2.7	0.410	7.4	0.34
3.1	0.340	8.2	0.31
2.7	0.464	5.8	0.42
2.9	0.433	6.9	0.38
2.7	0.347	7.6	0.34
2.2	0.424	7.6	0.31
2.5	0.421	6.8	0.33
		6.3	0.37

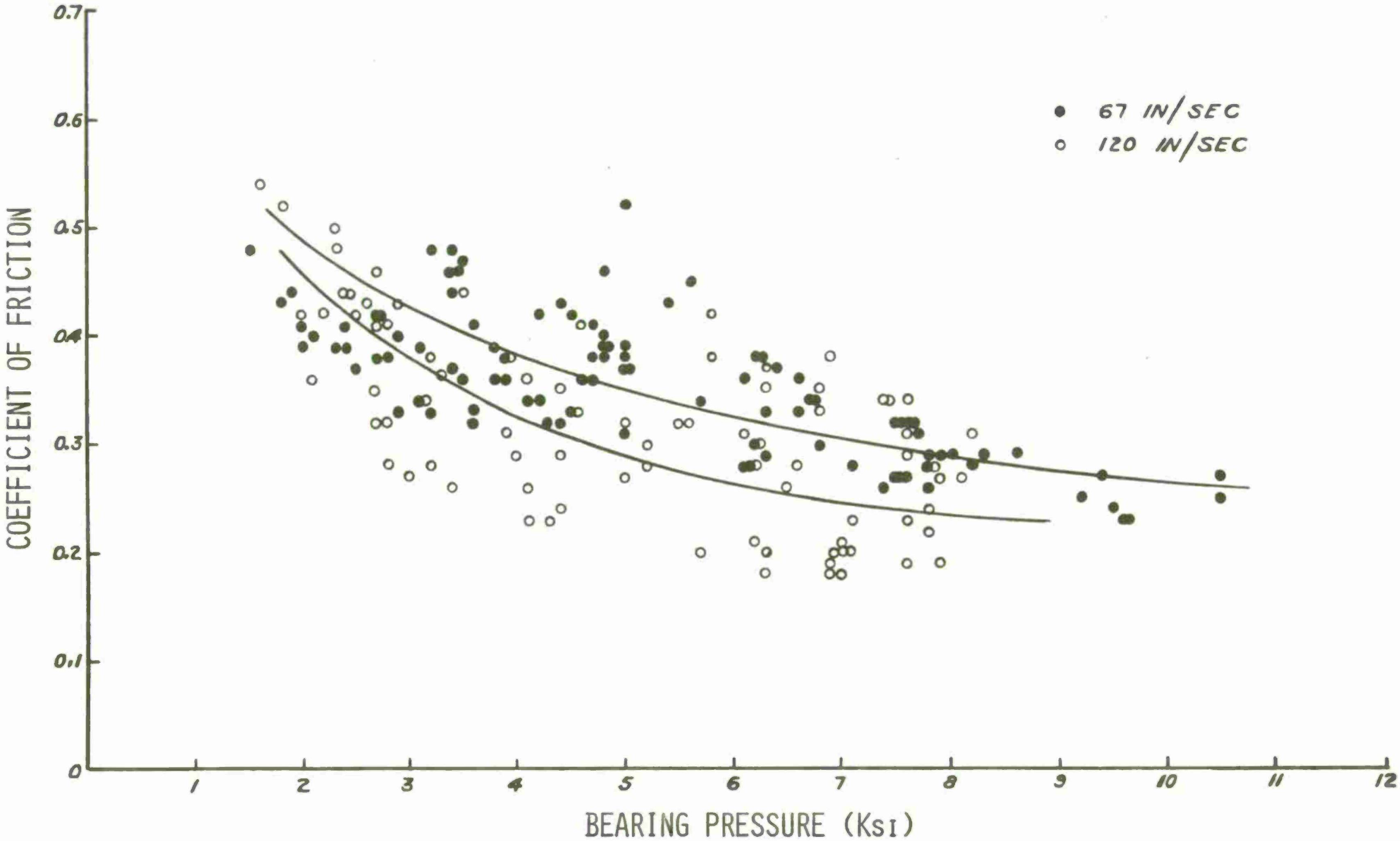

Figure 1. Friction coefficient of gilding metal sliding on AISI 4340 steel as a function of bearing pressure.

TABLE 3. FRICTION OF 7075 ALUMINUM ALLOY SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
10.2	0.249	8.4	0.286
9.9	0.260	8.6	0.292
10.3	0.267	8.9	0.298
10.2	0.281	8.9	0.314
10.6	0.291	9.3	0.303
10.3	0.298	9.4	0.290
10.3	0.298	9.3	0.303
10.3	0.304	9.3	0.305
8.7	0.243	9.4	0.301
9.2	0.243	9.3	0.309
9.7	0.251	9.3	0.307
9.9	0.262	9.4	0.306
10.0	0.272	4.6	0.306
9.8	0.286	6.1	0.312
9.9	0.300	7.4	0.306
9.9	0.317	6.8	0.309
10.1	0.308	6.9	0.328
9.5	0.251	6.9	0.323
9.7	0.259	7.9	0.316
9.9	0.263	7.9	0.316
9.7	0.280	8.0	0.322
9.9	0.285	8.3	0.296
9.8	0.291	8.6	0.295
4.8	0.295	8.5	0.293
7.0	0.276	8.5	0.298
8.7	0.283	8.4	0.299
9.5	0.288	8.4	0.291
9.9	0.282	8.4	0.290
10.2	0.280	8.3	0.296
10.0	0.292	8.3	0.263
10.3	0.264	8.4	0.282
10.3	0.271	8.3	0.296
10.7	0.273	8.3	0.294
10.6	0.277	8.3	0.296
10.6	0.282	8.5	0.276
10.7	0.283	8.4	0.275
4.3	0.298	8.4	0.282
6.4	0.303	8.4	0.288
7.6	0.309	8.7	0.275
8.5	0.292	3.7	0.325
8.4	0.289	6.2	0.326

TABLE 3. FRICTION OF 7075 ALUMINUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
6.4	0.334	1.9	0.339
6.3	0.313	3.7	0.313
6.6	0.314	3.8	0.326
7.2	0.296	3.5	0.330
7.2	0.294	4.1	0.320
7.4	0.303	4.0	0.328
7.4	0.298	4.1	0.320
7.4	0.293	4.1	0.324
7.4	0.293	4.3	0.314
7.7	0.303	4.6	0.291
7.4	0.302	4.4	0.307
7.4	0.305	4.4	0.307
7.1	0.315	4.7	0.288
3.9	0.307	4.3	0.314
5.6	0.303	4.5	0.293
5.2	0.323	4.5	0.293
5.4	0.319	4.1	0.329
5.6	0.307	4.1	0.320
6.6	0.281	2.8	0.343
6.2	0.287	3.1	0.321
6.2	0.298	3.4	0.320
6.6	0.281	3.1	0.327
6.4	0.279	3.4	0.304
6.7	0.281	3.3	0.299
6.5	0.288	3.5	0.308
6.6	0.284	3.7	0.306
6.4	0.290	3.5	0.303
6.6	0.300	3.5	0.316
6.6	0.306	3.8	0.304
6.6	0.290	3.5	0.321
4.1	0.300	3.5	0.321
5.2	0.301	3.4	0.333
4.3	0.304	3.6	0.317
5.6	0.280	3.5	0.339
4.5	0.327	3.5	0.339
5.6	0.292	2.3	0.319
4.7	0.333	2.3	0.327
5.8	0.284	2.2	0.320
5.5	0.288	2.2	0.320

TABLE 3. FRICTION OF 7075 ALUMINUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
2.0	0.305	2.4	0.322
2.3	0.319	2.2	0.320
2.5	0.337	2.0	0.332
2.6	0.309	2.1	0.321
2.8	0.322	9.2	0.267
2.3	0.339	9.5	0.294
2.9	0.318	9.5	0.324
2.5	0.331	9.7	0.318
2.5	0.324	9.7	0.316

TABLE 3. FRICTION OF 7075 ALUMINUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
6.9	0.280	5.4	0.32
7.8	0.288	5.9	0.30
6.7	0.313	6.1	0.30
7.8	0.302	6.3	0.30
7.2	0.307	4.3	0.306
7.2	0.291	5.6	0.32
7.2	0.312	6.7	0.31
7.4	0.31	6.0	0.32
6.7	0.31	5.9	0.32
7.6	0.31	6.6	0.30
4.8	0.306	7.2	0.30
4.3	0.297	7.0	0.32
5.0	0.31	8.3	0.296
5.0	0.29	8.3	0.310
4.7	0.32	8.7	0.295
4.8	0.30	9.1	0.277
5.5	0.32	9.3	0.272
5.2	0.32	7.7	0.312
3.1	0.303	8.1	0.312
2.4	0.355	7.9	0.312
3.4	0.299	6.1	0.305*
2.7	0.329	6.1	0.310*
3.2	0.304	6.9	0.330*
2.7	0.349	6.8	0.321*
3.6	0.277	6.8	0.290*
5.2	0.294	7.4	0.276*
5.5	0.29	4.6	0.304*
5.6	0.28	8.8	0.314*
6.0	0.29	9.7	0.279*
		9.2	0.323*

*Values determined using 0.156 in. diameter pin.

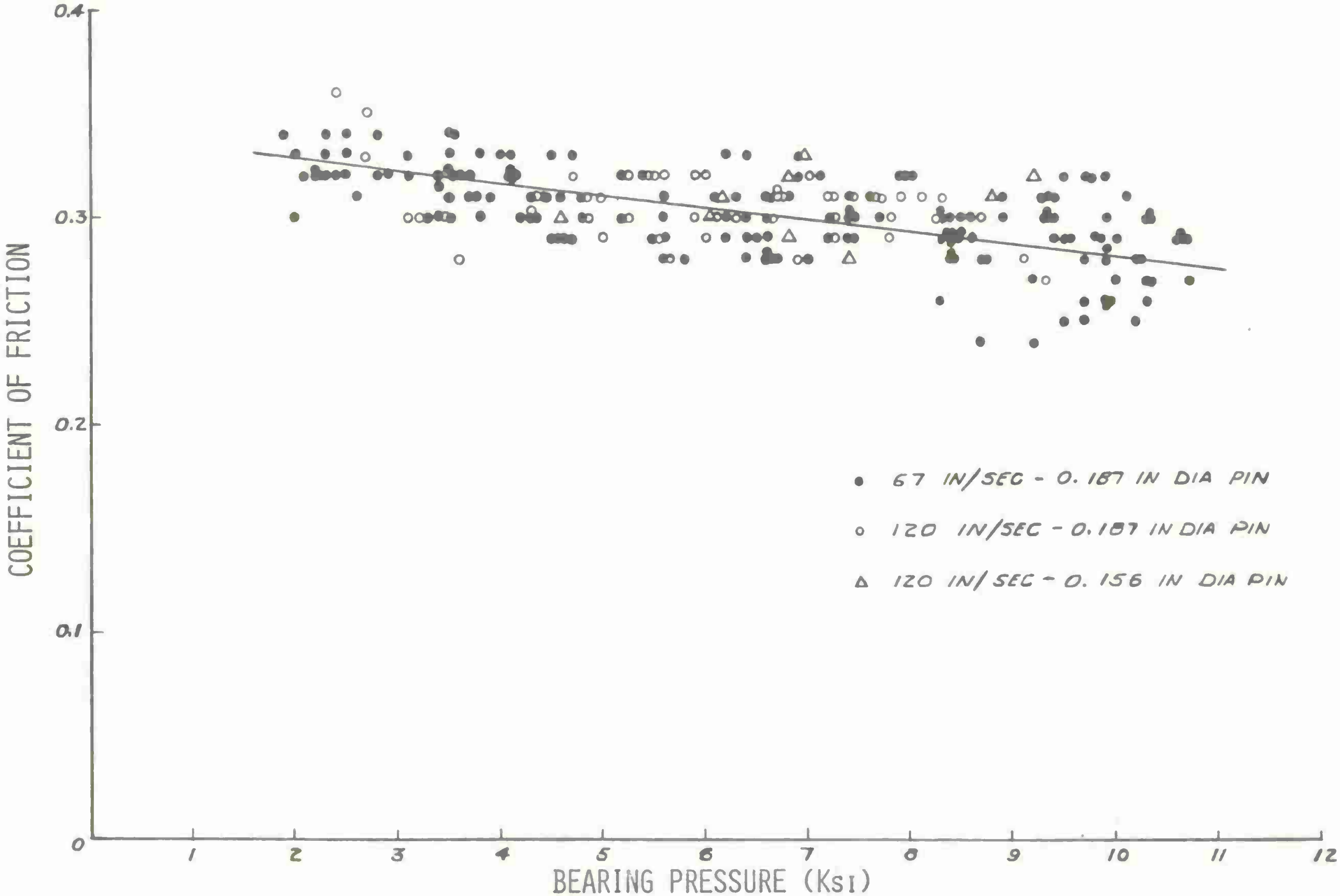

Figure 2. Friction coefficient of 7075 aluminum alloy sliding on AISI 4340 steel as a function of bearing pressure.

AZ61A Magnesium Alloy

Sliding was smooth with no oscillation and there was only a small amount of smooth transfer of magnesium to the steel. The wear rate was low.

The coefficient of friction was low and almost unaffected by bearing pressure. The same coefficient was obtained with both sliding velocities. It varied from about 0.12 at 2.0 Ksi to about 0.11 at 16 Ksi (see Table 4 and Figure 3).

Sintered Iron

The wear rate of sintered iron sliding on steel under these conditions was high and both load and friction force oscillated greatly. Under all but the lightest loads, there was a great deal of rough, strain-hardened iron transferred to the steel. This transferred iron was attached very firmly and was difficult to remove.

The coefficient of friction for this material was suprising low. It was higher for the lower sliding velocity and it decreased with increasing bearing pressure. Many of the materials investigated showed this kind of behavior. It probably varied only from about 0.11 at 5.0 Ksi to about 0.07 and 0.05 at 12.0 Ksi for velocities of 67 and 120 in/sec, respectively (see Table 5 and Figure 4).

TABLE 4. FRICTION OF AZ61A MAGNESIUM ALLOY SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
6.6	0.074	12.4	0.098
6.4	0.081	12.6	0.104
7.6	0.075	13.8	0.098
8.3	0.067	13.0	0.106
8.7	0.071	13.0	0.103
8.2	0.082	13.3	0.096
8.6	0.074	13.0	0.108
8.7	0.085	13.2	0.106
8.4	0.077	13.2	0.112
8.9	0.079	12.8	0.108
9.4	0.071	13.5	0.118
8.4	0.081	14.4	0.111
9.1	0.071	13.2	0.125
9.9	0.095	13.6	0.118
9.3	0.095	13.9	0.115
9.9	0.095	13.9	0.116
8.7	0.102	14.0	0.115
9.3	0.101	14.7	0.115
9.1	0.101	14.3	0.123
8.3	0.100	14.6	0.119
11.2	0.090	8.3	0.118
10.9	0.094	7.9	0.105
10.9	0.099	7.8	0.115
10.8	0.098	9.1	0.113
11.1	0.100	9.8	0.125
11.1	0.097	9.5	0.120
11.0	0.098	9.7	0.123
10.7	0.106	9.5	0.122
10.1	0.084	10.0	0.120
10.6	0.088	9.4	0.126
11.3	0.089	9.4	0.122
11.0	0.087	3.9	0.111
11.8	0.087	3.7	0.100
12.0	0.101	4.3	0.109
11.4	0.098	4.2	0.108
12.5	0.094	4.1	0.108
12.0	0.101	5.3	0.104
11.0	0.115	4.8	0.100
11.9	0.106	4.8	0.112
12.0	0.095	4.7	0.102
12.2	0.100	5.0	0.098

TABLE 4. FRICTION OF AZ61A MAGNESIUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
5.0	0.123	8.4	0.095*
4.6	0.111	8.3	0.106*
4.8	0.103	8.7	0.101*
4.8	0.107	8.2	0.106*
3.9	0.110	8.5	0.103*
3.2	0.106	8.6	0.102*
3.8	0.108	8.3	0.106*
3.6	0.118	8.0	0.110*
3.9	0.096	8.1	0.099*
4.6	0.105	8.2	0.097*
4.2	0.112	7.1	0.098*
4.4	0.111	8.3	0.096*
4.3	0.112	8.1	0.096*
4.6	0.105	9.1	0.088*
4.7	0.110	9.8	0.087*
4.4	0.111	10.3	0.088*
2.7	0.112	9.6	0.091*
2.5	0.104	10.7	0.092*
2.4	0.102	10.4	0.093*
2.9	0.103	10.4	0.095*
3.1	0.109	10.3	0.096*
3.4	0.109	10.3	0.096*
3.1	0.115	10.6	0.092*
3.3	0.105	9.7	0.101*
3.5	0.110	9.9	0.099*
3.1	0.120	10.2	0.096*
3.8	0.099	8.9	0.101*
3.5	0.099	9.9	0.104*
3.5	0.094	9.4	0.107*
3.5	0.094	10.7	0.102*
7.1	0.098*	10.7	0.114*
7.1	0.094*	11.4	0.111*
7.0	0.100*	10.7	0.119*
7.3	0.103*	12.2	0.113*
8.0	0.100*	11.4	0.118*
8.5	0.100*	11.7	0.115*

*Values determined using 0.156 in. diameter pin.

TABLE 4. FRICTION OF AZ61A MAGNESIUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
11.7	0.118*	13.3	0.099*
12.2	0.115*	13.4	0.108*
11.9	0.116*	14.2	0.110*
11.9	0.113*	14.1	0.112*
10.6	0.112*	14.2	0.111*
8.4	0.095*	14.5	0.114*
11.0	0.090*	15.0	0.119*
12.7	0.088*	15.4	0.122*
11.9	0.094*	14.2	0.124*
12.6	0.101*	14.0	0.126*
13.0	0.098*	13.7	0.122*
13.3	0.105*	10.3	0.106*
13.7	0.109*	11.3	0.113*
13.4	0.112*	12.7	0.116*
14.0	0.118*	12.4	0.126*
13.3	0.119*	13.2	0.118*
14.4	0.103*	14.5	0.116*
13.9	0.113*	15.4	0.122*
12.5	0.116*	15.8	0.121*
10.9	0.110*	15.0	0.125*
10.0	0.088*	15.9	0.120*
12.2	0.089*	15.9	0.124*
13.3	0.095*	15.5	0.126*
		14.8	0.126*

*Values determined using 0.156 in. diameter pin.

TABLE 4. FRICTION OF AZ61A MAGNESIUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
5.7	0.097	2.7	0.134
5.7	0.100	3.2	0.122
5.9	0.097	2.8	0.134
6.6	0.101	3.1	0.120
6.8	0.112	3.1	0.120
6.8	0.115	3.3	0.115
7.3	0.110	3.3	0.115
7.4	0.106	3.5	0.122
7.0	0.111	3.4	0.129
7.5	0.104	3.6	0.123
8.3	0.094	3.3	0.132
8.0	0.112	3.3	0.115
8.3	0.105	3.5	0.119
8.3	0.118	3.5	0.119
7.8	0.126	4.3	0.101
8.3	0.115	4.3	0.101
9.2	0.112	4.3	0.101
9.3	0.119	3.5	0.125
9.3	0.119	3.4	0.128
9.7	0.122	3.8	0.138
9.2	0.126	4.0	0.142
9.7	0.123	4.4	0.140
9.4	0.124	4.1	0.136
9.9	0.121	4.6	0.139
10.4	0.120	5.0	0.142
10.6	0.120	4.5	0.136
10.5	0.120	4.4	0.111
10.7	0.127	4.1	0.131
11.5	0.133	4.6	0.121
1.9	0.130	5.4	0.109
1.9	0.130	5.0	0.113
1.9	0.130	5.6	0.092
2.7	0.134	5.6	0.112
2.5	0.141	5.5	0.119
2.4	0.124	5.0	0.126
2.4	0.147	4.7	0.118
2.5	0.141	5.6	0.105
2.3	0.113	5.7	0.103
2.7	0.120	5.5	0.107
2.4	0.124	5.8	0.120

TABLE 4. FRICTION OF AZ61A MAGNESIUM ALLOY SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
5.5	0.122	9.3	0.111*
5.6	0.112	8.8	0.106*
5.8	0.112	7.6	0.096*
6.0	0.117	8.9	0.108*
6.8	0.103	9.5	0.101*
6.1	0.110	9.0	0.118*
6.6	0.100	9.4	0.102*
8.7	0.098*	9.7	0.118*
9.3	0.103*	10.1	0.117*
9.5	0.104*	12.3	0.121*

*Values determined using 0.156 in. diameter pin.

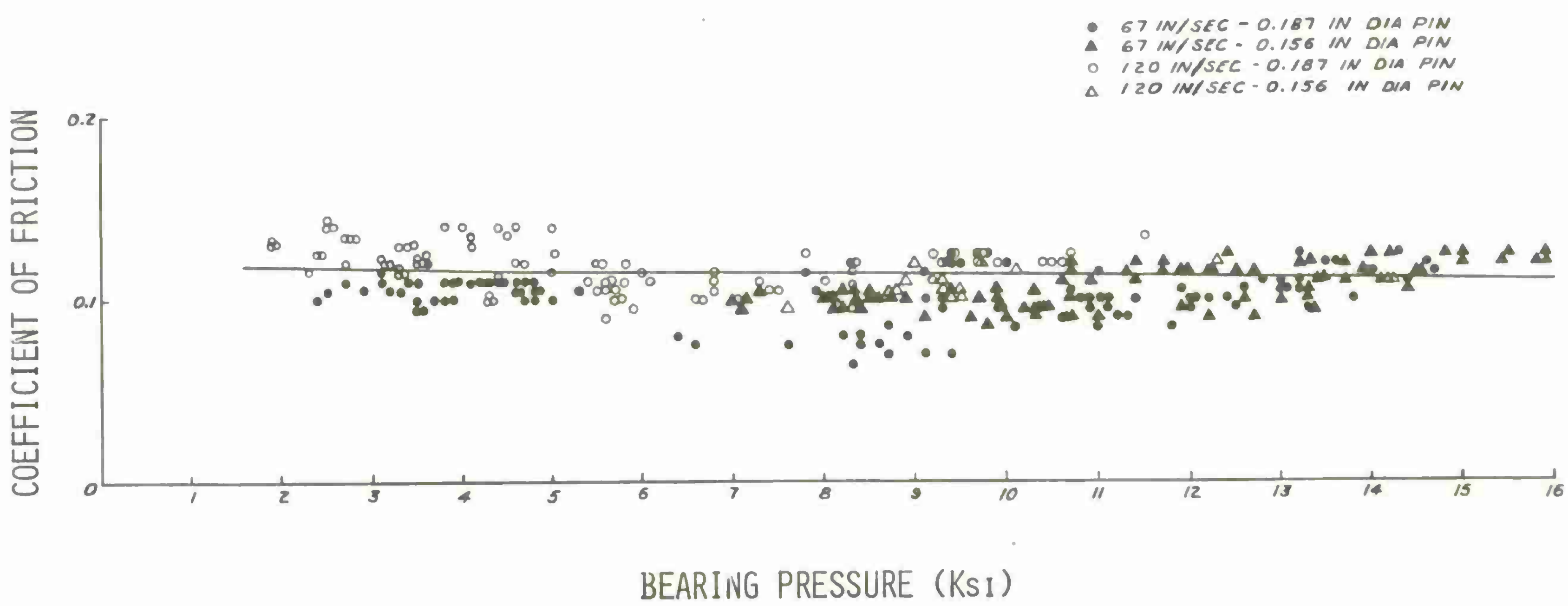

Figure 3. Friction coefficient of AZ61A magnesium alloy sliding on AISI 4340 steel as a function of bearing pressure.

TABLE 5. FRICTION OF SINTERED IRON SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
7.4	0.045	9.4	0.087
7.1	0.052	9.7	0.094
7.9	0.050	9.8	0.100
7.7	0.047	9.8	0.090
7.5	0.057	9.7	0.086
7.1	0.052	10.4	0.081
8.4	0.057	10.0	0.070
6.8	0.094	10.8	0.042
7.2	0.096	10.7	0.047
8.1	0.044	11.0	0.064
7.5	0.062	11.1	0.059
7.0	0.065	12.1	0.061
8.6	0.052	11.9	0.070
8.1	0.075	11.5	0.073
8.9	0.052	11.8	0.070
8.9	0.072	11.9	0.070
8.4	0.092	11.4	0.077
8.4	0.098	12.1	0.070
8.6	0.107	9.7	0.073
8.1	0.102	10.4	0.078
9.0	0.092	10.2	0.104
8.2	0.113	10.4	0.104
8.1	0.118	10.5	0.109
8.8	0.056	10.4	0.108
8.8	0.054	10.1	0.107
8.7	0.062	10.9	0.106
9.8	0.063	10.7	0.102
9.8	0.059	10.9	0.115
10.7	0.057	10.9	0.115
		10.0	0.115

TABLE 5. FRICTION OF SINTERED IRON SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
6.8	0.044	9.6	0.074
7.6	0.047	7.6	0.056
7.4	0.046	8.0	0.065
7.5	0.050	7.4	0.058
7.0	0.043	8.0	0.053
6.9	0.044	8.0	0.060
7.2	0.040	8.3	0.074
7.1	0.040	8.7	0.081
9.8	0.031	8.7	0.077
10.5	0.032	8.7	0.075
10.5	0.038	5.6	0.110
11.1	0.036	6.2	0.092
6.3	0.077	6.1	0.084
6.8	0.063	5.8	0.079
6.4	0.067	4.5	0.111
6.4	0.067	5.6	0.084
6.6	0.057	6.2	0.069
6.3	0.091	5.9	0.065
6.5	0.083	5.9	0.068
9.7	0.066	5.6	0.059
9.5	0.062	5.9	0.107
9.5	0.067	6.0	0.110
9.2	0.065	5.9	0.108
9.9	0.068	5.2	0.117
9.6	0.077	4.7	0.108

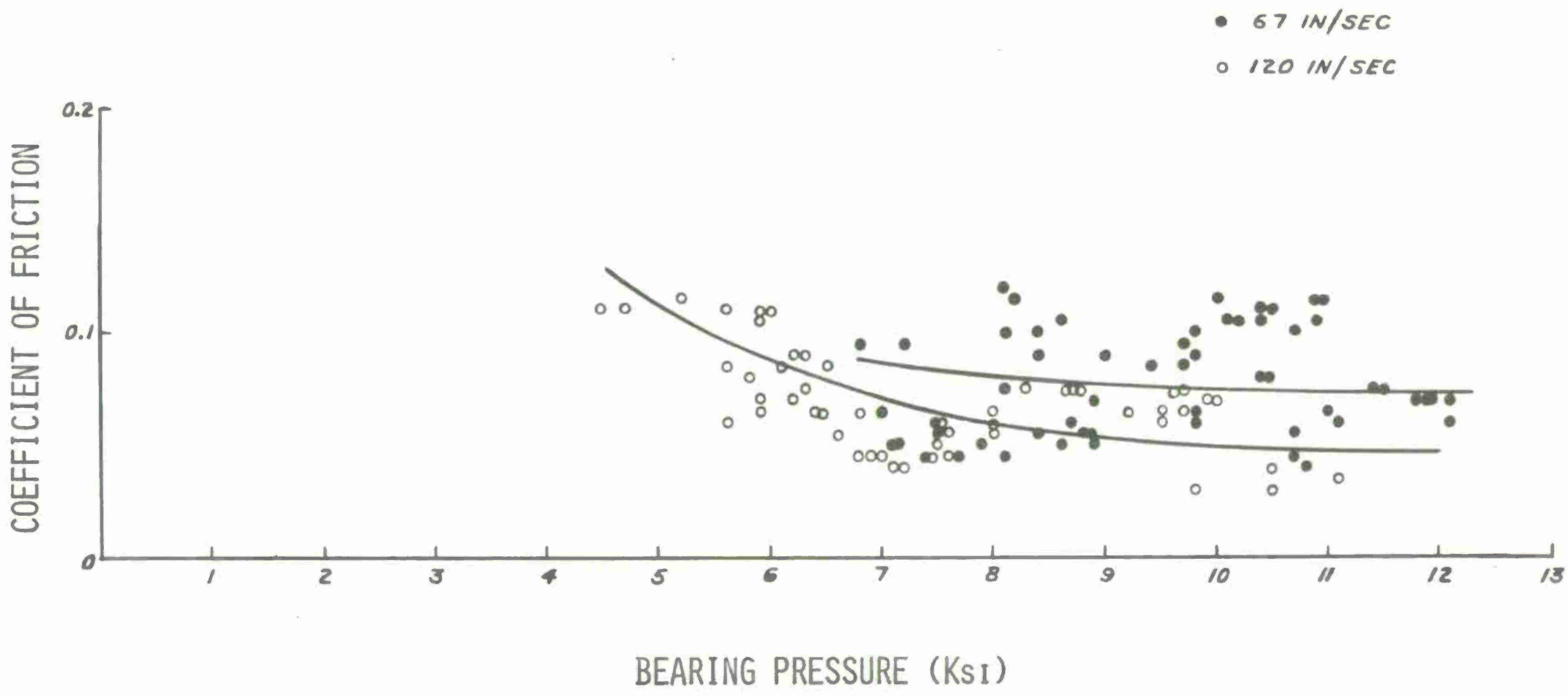

Figure 4. Friction coefficient of sintered iron sliding on AISI 4340 steel as a function of bearing pressure.

Soft Iron

The sliding characteristics of soft iron were essentially the same as those of sintered iron. If anything, there was greater transfer of iron to the steel disk. The coefficient of friction was difficult to measure because of the extreme oscillation of the oscilloscope traces.

The coefficient of friction showed a large effect of bearing pressure. It rapidly decreased from about 0.6 at 2.5 Ksi to a little over 0.2 at 7.5 Ksi. Both sliding velocities investigated appeared to give the same values (see Table 6 and Figure 5).

Nylon 6-6

The sliding of nylon on steel was smooth and the wear rate was low under the conditions of the experiments. There was only a small amount of material transferred to the steel disk.

Both sliding velocities investigated gave the same coefficients of friction. They decreased from about 0.21 at 2.5 Ksi to about 0.11 at 13 Ksi (see Table 7 and Figure 6).

Vulcanized Fiber

The wear rate of vulcanized fiber sliding on steel was high and a great deal of material was transferred to the steel disk in the form of lumps. These lumps of vulcanized fiber, of course, were not attached firmly to the steel as were the iron lumps.

TABLE 6. FRICTION OF SOFT IRON SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
3.3	0.38	3.2	0.36
3.5	0.34	3.6	0.30
3.6	0.35	3.2	0.33
4.1	0.30	3.1	0.39
3.8	0.33	3.8	0.40
4.1	0.32	3.1	0.43
4.1	0.36	4.0	0.32
4.0	0.38	4.2	0.32
3.2	0.44	4.5	0.30
3.9	0.41	4.7	0.33
2.7	0.42	4.5	0.35
3.3	0.34	4.6	0.39
2.8	0.43	3.8	0.45
3.5	0.36	4.6	0.38
3.0	0.41	4.1	0.41
3.3	0.40	4.0	0.41
3.8	0.37	4.0	0.45
3.4	0.42	4.5	0.42
3.3	0.44	4.3	0.37
3.3	0.30	4.4	0.38
2.8	0.32	4.4	0.39
3.4	0.30	4.4	0.41
3.3	0.33	4.7	0.40
3.2	0.30	4.0	0.44
3.3	0.33	4.4	0.44
3.4	0.33	4.7	0.39
		4.3	0.43

TABLE 6. FRICTION OF SOFT IRON SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec
(Values determined using 0.156 in. diameter pin)

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
3.4	0.42	5.6	0.26
2.7	0.54	6.0	0.26
3.3	0.45	5.9	0.26
4.6	0.22	6.5	0.24
3.6	0.54	7.2	0.24
3.5	0.52	4.0	0.24
2.1	0.56	4.3	0.24
2.9	0.53	3.7	0.30
4.4	0.39	4.3	0.26
4.1	0.41	5.8	0.27
3.2	0.64	7.2	0.23
5.9	0.23	7.2	0.21
5.1	0.22	6.9	0.26
5.8	0.21	3.3	0.37
6.2	0.23	2.4	0.52
6.2	0.23	2.6	0.52
6.2	0.23	2.8	0.42
5.3	0.31	3.0	0.44
5.6	0.23	2.8	0.43
6.0	0.30	2.5	0.53
5.2	0.33	2.2	0.58
3.1	0.53	2.8	0.46
4.1	0.57	2.6	0.49
		3.0	0.43

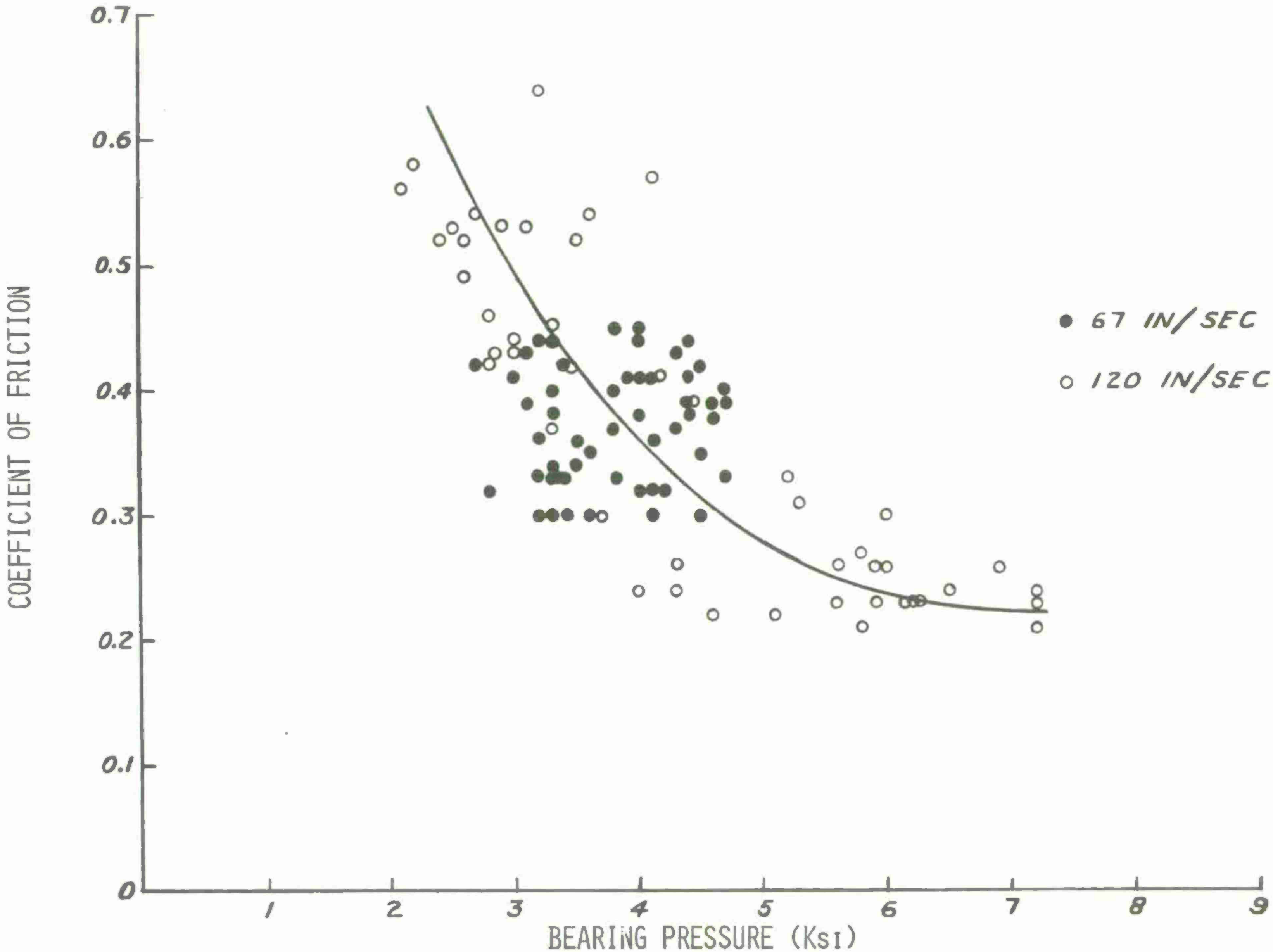

Figure 5. Friction coefficient of soft iron sliding on AISI 4340 steel as a function of bearing pressure.

TABLE 7. FRICTION OF NYLON 6-6 SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
8.3	0.116	11.7	0.117
8.6	0.119	11.4	0.121
8.5	0.115	12.1	0.114
9.8	0.106	12.2	0.113
9.4	0.116	12.0	0.115
9.4	0.120	12.2	0.113
9.6	0.118	11.9	0.116
9.4	0.120	9.2	0.140
8.9	0.127	9.2	0.142
9.2	0.123	9.6	0.140
8.0	0.127	9.6	0.144
8.5	0.124	10.3	0.139
9.0	0.125	10.8	0.137
9.3	0.126	11.6	0.123
9.8	0.119	11.8	0.123
9.4	0.128	11.7	0.123
10.0	0.123	11.6	0.123
10.4	0.120	11.9	0.121
11.0	0.119	10.8	0.130
10.4	0.126	11.3	0.121
10.4	0.126	11.9	0.118
10.4	0.126	11.6	0.120
6.2	0.136	11.5	0.121
7.6	0.128	11.9	0.118
8.2	0.127	11.7	0.120
8.8	0.125	4.3	0.153
9.2	0.126	4.1	0.170
10.0	0.123	4.8	0.168
11.0	0.114	4.8	0.168
11.3	0.115	4.9	0.163
11.2	0.114	4.7	0.174
11.4	0.113	5.2	0.164
11.2	0.114	4.9	0.177
12.2	0.113	4.8	0.179
11.7	0.117	5.1	0.174
11.4	0.121	5.3	0.169
12.1	0.114	4.9	0.182
12.2	0.113	4.9	0.181
12.0	0.115	3.5	0.168
12.2	0.113	3.9	0.164

TABLE 7. FRICTION OF NYLON 6-6 SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
3.5	0.179	4.1	0.167
4.0	0.176	4.4	0.159
4.1	0.176	4.3	0.165
3.7	0.191	6.1	0.158
3.9	0.188	5.7	0.169
3.7	0.194	5.7	0.169
4.1	0.188	6.6	0.159
3.9	0.186	6.8	0.159
3.9	0.188	7.1	0.157
3.9	0.188	6.8	0.163
3.0	0.173	7.3	0.155
3.1	0.167	6.9	0.164
2.9	0.180	6.8	0.167
2.9	0.174	6.8	0.167
2.6	0.169	6.8	0.162
2.9	0.174	7.6	0.136
2.9	0.174	7.6	0.149
2.7	0.179	7.8	0.152
2.7	0.179	7.7	0.132
4.9	0.153	8.5	0.122
5.4	0.146	8.8	0.119
5.5	0.150	8.4	0.122
5.9	0.146	8.4	0.126
5.7	0.153	8.4	0.122
5.9	0.155	8.3	0.123
6.2	0.154	3.7	0.160
5.8	0.164	3.5	0.201
5.8	0.164	3.2	0.198
5.8	0.167	3.7	0.196
5.8	0.167	3.5	0.212
6.0	0.164	4.1	0.207
3.6	0.155	4.3	0.196
4.0	0.157	3.9	0.217
4.4	0.152	3.9	0.213
4.3	0.148	3.7	0.215
4.3	0.150	3.5	0.226
4.7	0.144	3.7	0.212
4.4	0.157	3.7	0.215
4.5	0.155	3.8	0.210

TABLE 7. FRICTION OF NYLON 6-6 SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
3.7	0.203	3.1	0.184
2.3	0.188	2.8	0.182
2.4	0.186	2.6	0.180
2.6	0.170	2.4	0.184
2.7	0.182	2.4	0.199
3.1	0.180	2.7	0.209
		2.4	0.206

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
2.3	0.172	5.5	0.142
2.4	0.184	5.7	0.149
2.7	0.166	5.7	0.147
2.8	0.167	6.0	0.158
2.8	0.167	6.6	0.153
2.8	0.167	6.2	0.162
2.9	0.181	6.1	0.164
3.3	0.183	6.9	0.161
3.2	0.192	7.0	0.158
3.7	0.184	8.4	0.133
3.7	0.189	8.6	0.129
3.7	0.189	8.5	0.130
3.7	0.187	8.5	0.130
4.5	0.158	7.6	0.125
4.1	0.172	7.9	0.129
4.3	0.166	8.3	0.125
4.6	0.168	8.6	0.117
4.9	0.171	9.2	0.115
4.2	0.180	9.6	0.116
4.9	0.145	10.4	0.109
4.9	0.149	10.6	0.110
5.1	0.147	10.8	0.108

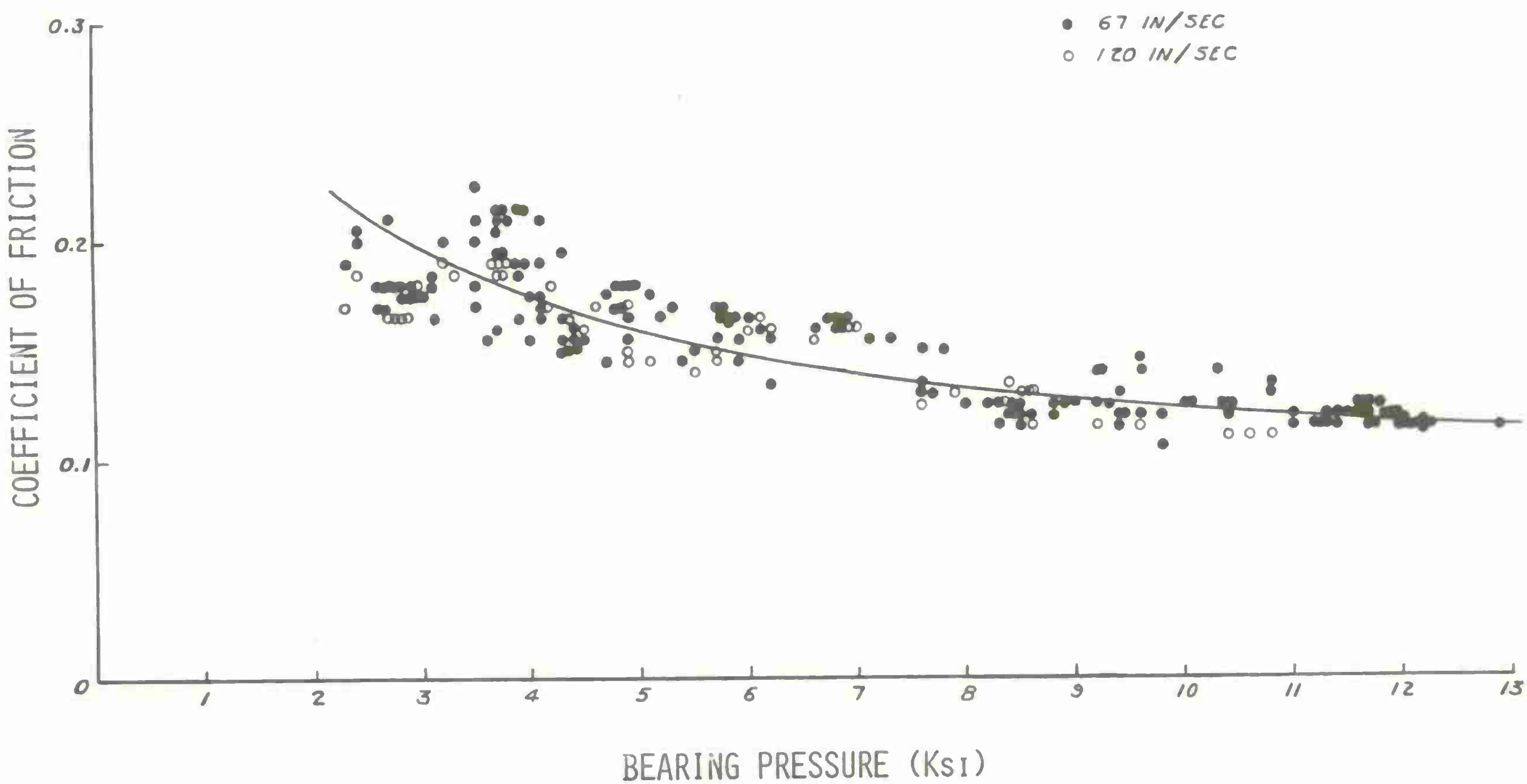

Figure 6. Friction coefficient of nylon 6-6 sliding on AISI 4340 steel as a function of bearing pressure.

Sliding velocity had a great effect on the friction of this material. At a velocity of 67 in/sec, the coefficient of friction decreased slightly from about 0.18 at 2.5 Ksi to about 0.16 at 9.0 Ksi. However, at a velocity of 120 in/sec, the coefficient of friction rapidly fell to about 0.05 at just 7.5 Ksi (see Table 8 and Figure 7).

CONCLUSIONS

It is possible to draw a number of conclusions and make a number of conjectures about the engraving and initial travel of cannon projectiles from the results of this laboratory study. A comparison of the different sliding characteristics and friction coefficients of band and potential band materials provides insight into the behavior of projectiles and will help to allow the design of rotating bands without the expensive extensive firing of an actual cannon.

1. Gilding metal has a comparatively high coefficient of friction at low load (0.50) but this would have an effect only as each portion of the band begins to engrave. During most of the engraving the coefficient of friction would be expected to be about 0.21.

2. Rotating bands made of the aluminum alloy would engrave smoothly and provide obturation similar to that of gilding metal bands. However, the coefficient of friction would be somewhat greater; it would probably be about .25 during engraving. This would result in an increased "shot-start" pressure which would have to be taken into account in the design of the bands and/or propelling charge.

TABLE 8. FRICTION OF VULCANIZED FIBER SLIDING ON AISI 4340 STEEL

Sliding Velocity 67 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
2.2	0.169	5.7	0.188
3.0	0.167	5.9	0.184
3.0	0.173	5.9	0.184
2.9	0.178	6.1	0.180
3.4	0.168	6.1	0.180
3.6	0.160	6.1	0.180
3.7	0.160	6.2	0.190
3.7	0.176	5.9	0.191
3.8	0.180	5.8	0.186
3.6	0.179	5.9	0.185
3.8	0.180	5.8	0.189
3.3	0.181	5.9	0.193
3.8	0.180	5.8	0.189
3.6	0.174	5.9	0.193
3.2	0.175	6.5	0.191
4.2	0.192	7.0	0.176
3.8	0.198	7.1	0.173
4.2	0.193	6.7	0.187
4.4	0.187	7.4	0.178
5.1	0.183	7.2	0.183
4.4	0.189	7.1	0.186
4.9	0.184	7.1	0.188
4.9	0.184	6.6	0.199
4.6	0.177	7.0	0.188
4.8	0.187	7.4	0.173
4.6	0.193	7.3	0.181
4.6	0.193	7.2	0.183
4.6	0.191	7.3	0.181
4.4	0.202	7.8	0.180
5.5	0.188	7.7	0.183
4.5	0.200	8.9	0.168
5.5	0.188	8.3	0.178
5.7	0.188	8.5	0.163
		8.6	0.161

TABLE 8. FRICTION OF VULCANIZED FIBER SLIDING ON AISI 4340 STEEL (CONT)

Sliding Velocity 120 in/sec

Bearing Pressure (KSI)	Coef. of Friction	Bearing Pressure (KSI)	Coef. of Friction
7.1	0.056	4.2	0.138
6.0	0.064	4.5	0.131
7.0	0.060	4.8	0.129
7.5	0.058	4.0	0.132
7.4	0.059	4.6	0.131
7.3	0.062	4.5	0.142
2.5	0.160	4.2	0.138
2.3	0.176	4.2	0.151
2.3	0.168	4.4	0.147
3.0	0.165	4.8	0.132
2.9	0.170	4.3	0.141
2.6	0.183	5.1	0.137
2.9	0.164	5.1	0.137
3.2	0.150	4.9	0.142
2.8	0.174	4.8	0.145
3.1	0.180	4.8	0.144
3.2	0.183	2.6	0.153
3.1	0.180	2.1	01.58
3.0	0.185	2.1	0.158
3.1	0.180	2.3	0.170
3.1	0.180	1.7	0.192
4.0	0.123	1.5	0.182
3.3	0.151	1.4	0.180
4.1	0.120	1.6	0.164
4.0	0.114	1.6	0.164
4.0	0.114	1.5	0.170
3.9	0.125	1.9	0.175
4.4	0.125	1.9	0.175
4.6	0.116	2.5	0.165
4.4	0.134	2.5	0.167
3.8	0.153	2.4	0.166
3.8	0.158	2.3	0.170
4.8	0.140	2.5	0.173

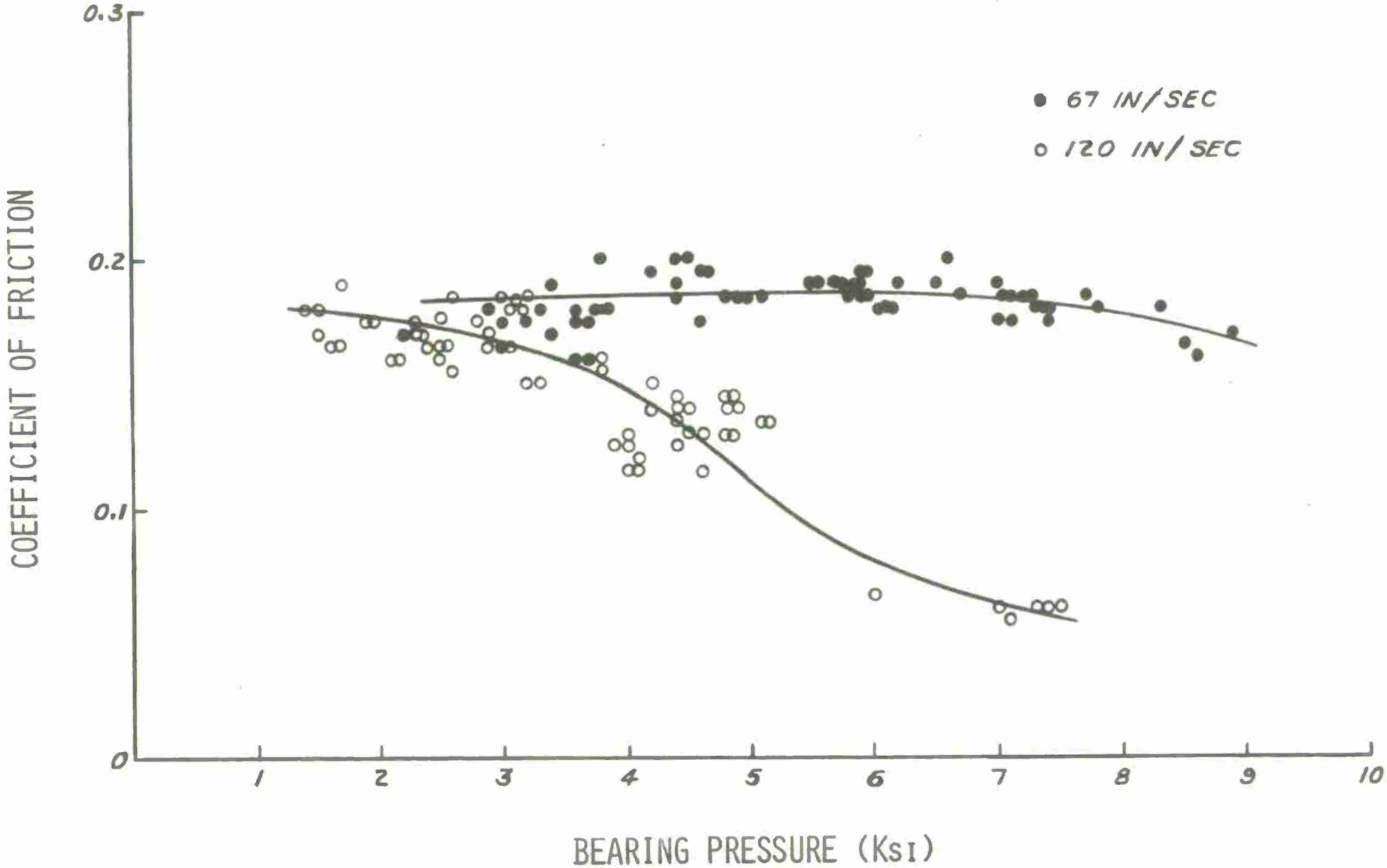

Figure 7. Friction coefficient of vulcanized fiber sliding on AISI 4340 steel as a function of bearing pressure.

3. The magnesium alloy would give rotating bands which would engrave smoothly and provide good obturation and which would have a coefficient of friction of only about 0.11.

4. The friction characteristics of soft and sintered iron are entirely different. Rotating bands made of these two materials are certainly not equivalent but both irons would be expected to give bands with poor engraving behavior and poor initial obturation. It would also be expected that transferred iron on the bore in the region of the origin-of-rifling would create a problem. Sintered iron bands would be expected to have an engraving friction coefficient as low as that for melt lubrication, 0.05. Soft iron, on the other hand, has an extremely high low-pressure friction but the coefficient of friction for most of the engraving would be expected to be about the same as that for gilding metal.

5. Nylon 6-6 rotating bands would be expected to give smooth engraving and very good initial obturation. This is in agreement with observations with actual cannon. The coefficient of friction during engraving would be expected to be about 0.11.

6. Vulcanized fiber rotating bands would be expected to give poor engraving behavior and poor initial obturation. However, the coefficient of friction would rapidly fall from an initial value of about 0.18 to a value as low as that of melt lubrication, 0.05.

While the relatively low-speed pin-on-disk experiments provide valid friction and wear data for the first inch of projectile travel, it must be cautioned that this data cannot be used as a guide to friction and wear of rotating bands during their entire travel down a cannon tube. The wear mechanism after the first inch or so of travel is a surface melting and so is entirely different from the initial wear mechanism.

REFERENCES

1. Montgomery, R. S., Surface Melting of Rotating Bands, Wear 38, 235-243 (1976).

2. Montgomery, R. S., Projectile Lubrication by Melting Rotating Bands, Wear 39, 181-183 (1976).

3. Montgomery, R. S., Friction and Wear at High Sliding Speeds, Wear 36, 275-298 (1976).

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